STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

THE EFFECT OF VARYING COMPACTIVE EFFORT IN RELATIVE COMPACTION TESTS

63-25

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Department of Public Works
Division of Highways
Materials and Research Department

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Mr. J. F. Jorgensen
Construction Engineer
Construction Department
Sacramento, California

Dear Sir:

Submitted for your consideration is:

REPORT

of

THE EFFECT OF VARYING COMPACTIVE EFFORT

in

RELATIVE COMPACTION TESTS

Study made by .... Foundation Section
Under general supervision of .... T. W. Smith
Work supervised by .... W. S. Maxwell
J. A. Cechetini
Report prepared by .... W. S. Maxwell

Very truly yours,

JOHN L. BEATON
Materials & Research Engr.

Attach
cc: LRGillis:WLWarren
JCObermuller:JBWatson
HKTaylor:GDillon
VYoder

Introduction

This report pertains to a comparison of the densities of test specimens compacted with varying moisture contents and varying compactive efforts, in the standard compaction apparatus and in the Hveem proposed apparatus currently in an experimental status.

The work was requested by Construction Engineer J. F. Jorgensen in correspondence dated August 8, 1963, and September 12, 1963.

A number of similar studies employing the standard apparatus alone or in conjunction with various compaction devices have been conducted in the past. One in 1955 involving eleven soil types was included in a 1957 paper by F. N. Hveem entitled "Maximum Density and Optimum Moisture of Soils - What Do These Terms Mean?" A more recent but very limited comparison using two soil types and the standard apparatus was reported in 1961. Others have been performed as a part of various special investigations.

Scope

Development of test compactive effort vs density data was the objective. Evaluation of the design, effectiveness or operation of the test apparatus was not involved.

Test samples of aggregate subbase and of roadway excavation were compacted by 10, 15 and 20 tamper blows per layer, respectively, in each apparatus. In addition, the roadway excavation was compacted by 25 blows per layer in the standard apparatus for reasons to be explained.

The projects, soil types and test results are individually discussed in this report followed by reviews of combined test results for each compactive effort.

Test Apparatus

In the standard apparatus described and illustrated in Test Method No. Calif. 216 a 2-7/8" diameter and average 11" compacted height sample is compacted in 5 layers.

In the experimental apparatus a 6" diameter by 4" compacted height sample is compacted in 2 layers. Because of a round center shaft approximately 2" in diameter the net sample volume of .058 cu. ft. is not as large as is indicated by the mold dimensions, but it is still considerably larger than the .041 cu. ft. standard sample.

Each apparatus employs an impact tamper arrangement and a force of 10 lbs. with an 18" drop distance. While not of the same shape the areas of the tamper faces are equal.

Due to the difference in the number of layers and in the sample volume, the compactive effort per cubic foot of sample is less for any given number of tamper blows per layer in the experimental apparatus than in the standard apparatus. For 20 blows per layer the average foot-pounds per cubic foot is 10,000 for the experimental mold and 36,500 for the standard mold.

Contract 63-4T13C7-F - Test Sections

The contractor on this project at Santa Rosa experienced difficulty in consistently attaining 95% relative compaction on the aggregate subbase. On-the-job test section rolling failed to produce satisfactory results and a Change Order lowering the specified minimum relative compaction to 93% was approved. At the time of the field study and test section rolling it was suspected that material degradation and/or high absorption was affecting the test results. Contract operations could not be suspended awaiting a laboratory analysis and under the circumstances it was not deemed appropriate to question the validity of the tests.

Subsequent investigation revealed that when the computed compensation for test oversize material was based on oven-dry specific gravities, in strict compliance with Test Method No. 216, the test values for the special test sections were 95%, or slightly higher, in 6 of the total of 9 tests for all sections including one with questioned adequacy of compaction. For the thoroughly rolled sections 5 out of 6 tests showed 95% R.C., or slightly higher.

Wide variation in material characteristics precluded the use of occasional check specific gravities by the oven-dry method, and it was not practical to attempt such a procedure for each control test. Under these conditions field testing personnel had no alternative other than to resort to saturated surface-dry specific gravities to compute the rejected oversize compensation. Normally this substitution of gravities would have been entirely acceptable for construction control, but due to the light gravities of 2.11 - 2.19 and high absorption of 10% - 12% for the + 3/4" aggregate this practice lowered the % R.C. final test values. The on-the-site tests for the special rolling sections were also run by field methods because it was not feasible to do otherwise at the time.

While the above discussed construction compaction problem and anlysis is not a part of the specific study reported herein it is pertinent to an evaluation of construction compactability vs control test compactive effort and test results. Also, the first material to be subjected to the 10-15-20 blows per layer test compaction was obtained from the special rolling sections.

Sack samples were initially treated at the laboratory in a routine manner. The material was separated on the 3/4" sieve and the retained fraction was processed in a device designed to remove the fines adhering to the coarse particles. The fines so removed were then placed in a container with the corresponding fraction of the original sample. As a result the + 3/4" was cleaner and the - 3/4" was somewhat finer than would be the case in the field as deposited on the grade. Furthermore, in the area of the special rolling sections the subbase had been spread and compacted by routine contractor operations prior to the field study and then removed, respread, and recompacted for the special trial rolling. This is not representative of construction practice where the material is worked only once but the spread was temporarily shut down at the time of the field study making it impossible to duplicate normal operations. Regardless, this material was compacted with the stipulated compactive efforts in both the standard and the experimental test devices.

To avoid confusion in appraising the following subject matter and test data it is especially noted at this time that all 10-15-20 blows per layer compaction specimens were assumed to represent 100% passing the 3/4" sieve material; therefore, the oversize compensation is not applicable in any test instance throughout the remainder of this report.

The plotted test data for the samples from the job special rolling sections are presented in Figure I. For each compactive effort the experimental apparatus attained roughly 6 lbs./cu.ft. higher maximum density.

Contract 63-4T13C7-F - Sta. 209

As has been explained the material sampled from the special rolling sections was not truly representative of material as normally delivered to the grade for spreading and compacting. For this reason samples of material dumped by trucks hauling directly from the pit were later obtained at Station 209. These samples were not submitted to the refined laboratory preparation but were handled in the same manner as in a good construction field laboratory. When compacted in both the standard and experimental devices the results were as shown in Figure II. For no apparent reason the relationship between standard and experimental curves is reversed from Figure I with the standard apparatus showing higher maximum densities by about 3 lbs./cu.ft. for the 15 and 20-blow curves. Based on grading analysis the samples of Figure II were slightly coarser and the sand content was slightly higher, i.e., 76% sand, 16% silt, 8% clay compared to 70% sand, 22% silt, 8% clay for Figure I samples.

A question may arise as to why the curves for both testing devices show lower maximum densities in Figure II than in Figure I for material from the same pit. In addition to the foregoing described differences in the handling of the material on the grade and in the testing operations, which may or may not have affected the end test results, there was a difference in the specific gravities of the two groups of test samples.

Specific Gravity	Figure I Samples	Figure II Samples
Coarse	2.10	1.93
Fine	2.52	2.48

Contract 63-4T13C13-I

Field engineering personnel advised that the aggregate subbase on this project between Danville and Walnut Creek was being compacted to 95% R.C. without difficulty. A bulk sample was obtained adjacent to the compacted grade but outside the limits of construction compactor coverage.

The plotted test results appear in Figure III. The curves for the standard apparatus denote test maximum densities approximately 3.5 lbs./cu.ft. higher for each compactive effort than is indicated by the experimental apparatus curves.

Contract 64-1T13C2-F

Samples of predominately silty soil from the top 6 feet of the embankment that slipped out on this project near McKinleyville were included in the test comparisons. According to the curves of Figure IV the test maximum densities for the standard apparatus ranged 8 to 11 lbs./cu.ft. higher than the densities reported for the experimental apparatus.

During the placement of the embankment the majority of the routine compaction control test results were 90% R.C., or higher, but the validity of these tests is debatable due to the saturated, unstable condition of the material. There was evidence of embankment densities well below 90% R.C.

Silt often creates a construction problem and an embarrassing situation. When the moisture content exceeds the grade optimum the area is very apt to become obviously unstable with quaking and shifting under construction equipment, but still test 90% R.C., or higher. Were it feasible to vary compaction specifications with soil types a more restrictive density and water control for silt would be appropriate. Lowering the density and raising the moisture content by reducing control test compactive effort could lead to more trouble on the job.

Moisture contents of 17.7% to 19.2% were reported for 6 out of a total of 10 determinations performed during construction of the embankment that failed under its own weight, and 4 of the 6 were in the 17.7% - 17.9% range. A test optimum moisture content of 16.2% is shown for the 20-blow procedure proposed for the experimental apparatus.

Two test specimens were compacted with 25 blows per layer in the standard apparatus in addition to the 10-15-20 blows per layer series. It has been found on construction test sections that very little increase in density results from additional rolling of an area that has been properly compacted with 6 to 8 compactor coverages. As is apparent in Figure IV increasing the blows to 25 did not raise the density nearly as much as did the increases from 10 to 15 or 15 to 20 blows.

Combined Curves

The 10-blow curves for each soil have been grouped in Figure V. Similar grouping for the 15-blow and 20-blow curves are displayed in Figures V and VI, respectively. The number of the Figure from which any given curve has been excerpted is noted adjacent to the subject curve.

Test Compactive Effort vs. Specified % R.C.

The effect of reducing the test compactive effort and raising the specified minimum relative compaction has been considered on several past occasions, with special attention in 1955 when it was decided to eliminate the construction compactor requirements and to rely solely on end result control on contracts.

In the following tabulation the density control for the contract specified minimum relative compaction by the standard test is shown with the corresponding density control by the 20-blow experimental apparatus for 100% R.C., 95% R.C., and 90% R.C., respectively. The number of the attached Figure illustrating the moisture-density curves is included for reference.

Fig. No.	Material Type	Currently Specified Control % RC	Currently Specified Control Lbs./c.f.	Experimental Control Densities - Lbs./c.f. 100% RC	Experimental Control Densities - Lbs./c.f. 95% RC	Experimental Control Densities - Lbs./c.f. 90% RC
I	Subbase	95	105	117	111	105
II	"	95	100	102	97	92
III	"	95	139	140	133	126
IV	Rdy. Exc. (silt)	90	115	116	111	105

As has been stated Figure I represents the sole instance in which the experimental apparatus curves denoted higher control density than did the standard apparatus curves. With the single exception of the values of Figure I it is evident in the above tabulation that the end result density by 100% RC experimental apparatus control was the same for both the subbases and the roadway excavation silt as is achieved by the currently specified control.

Insofar as varying the compactive effort in the standard test is concerned, it is apparent that the effect of decreasing the blows per layer varies with the type of soil. In Figure III the interval between the 10-15-20 curves is different than for Figure IV and especially the interval between the respective 15 and 20-blow curves.

For any compaction test apparatus of record lower compactive effort on the more difficult to handle fine-grained soils is accompanied by higher test optimum moisture contents. While it is recognized that the test optimum moisture content is not necessarily the grade optimum it is an approximation that influences contractors and engineering personnel in the application of water, and lower earthwork density permits higher water content.

The relationships between test compactive efforts and test optimum moisture contents for various test efforts on a silty clay and a sandy silty clay are depicted on attached Sheets "A" and "B". The deficiencies of low compactive effort tests is evidenced by the abandonment by many organizations of the old standard AASHO in favor of the modified AASHO. It is doubtful that the silty clay of Sheet "A" could be spread and rolled into a stable grade at the moisture content corresponding to standard AASHO test optimum.

As has been stated additional rolling of a construction grade that has been properly processed and compacted with reasonable effort does not materially increase the density. Likewise, in control tests the 56,000 ft. lbs./cu.ft. total effort of the modified AASHO does not result in a significant increase in density over the average 37,000 ft. lbs./cu.ft. of the California Impact, but the increase in density from the low 12,000 ft. lbs./cu.ft. of the old AASHO to the California effort is of consequence.

Summary and Conclusions

Test samples of aggregate subbase, Class II, and of a silt roadway excavation were compacted in the standard apparatus and in a new experimental design apparatus.

To investigate the effect of varying the test compactive effort each soil type was compacted by 10, 15 and 20 tamper blows per layer, respectively, in each test apparatus.

For any given number of tamper blows per layer the total compactive effort per test sample is less in the experimental apparatus than it is in the standard apparatus.

With reference to Figures II thru IV the experimental apparatus consistently attained lower test maximum densities than did the standard apparatus on both the subbases and the silt.

The reversal of the relative positions of the experimental apparatus curves and the standard apparatus curves on the subbase material as displayed in Figures I and II cannot be reconciled. In 3 of the 4 test groups 100% RC by the experimental apparatus procedure and the current standard specifications percent relative compaction procedure resulted in the same job control density.

Lower test compactive efforts on fine-grained soils are accompanied by higher test optimum moisture contents and raising the specified percent relative compaction does not alter the test optimum moisture content.

It is doubtful that some soils can be worked on construction at the test optimum moisture content indicated by low compactive effort tests, e.g., standard AASHO.

Abandonment of standard AASHO by many organizations in favor of higher density control is evidence of the deficiencies of low compactive effort tests.

Data developed in the current and in past studies fail to justify revision of the standard test compactive effort.

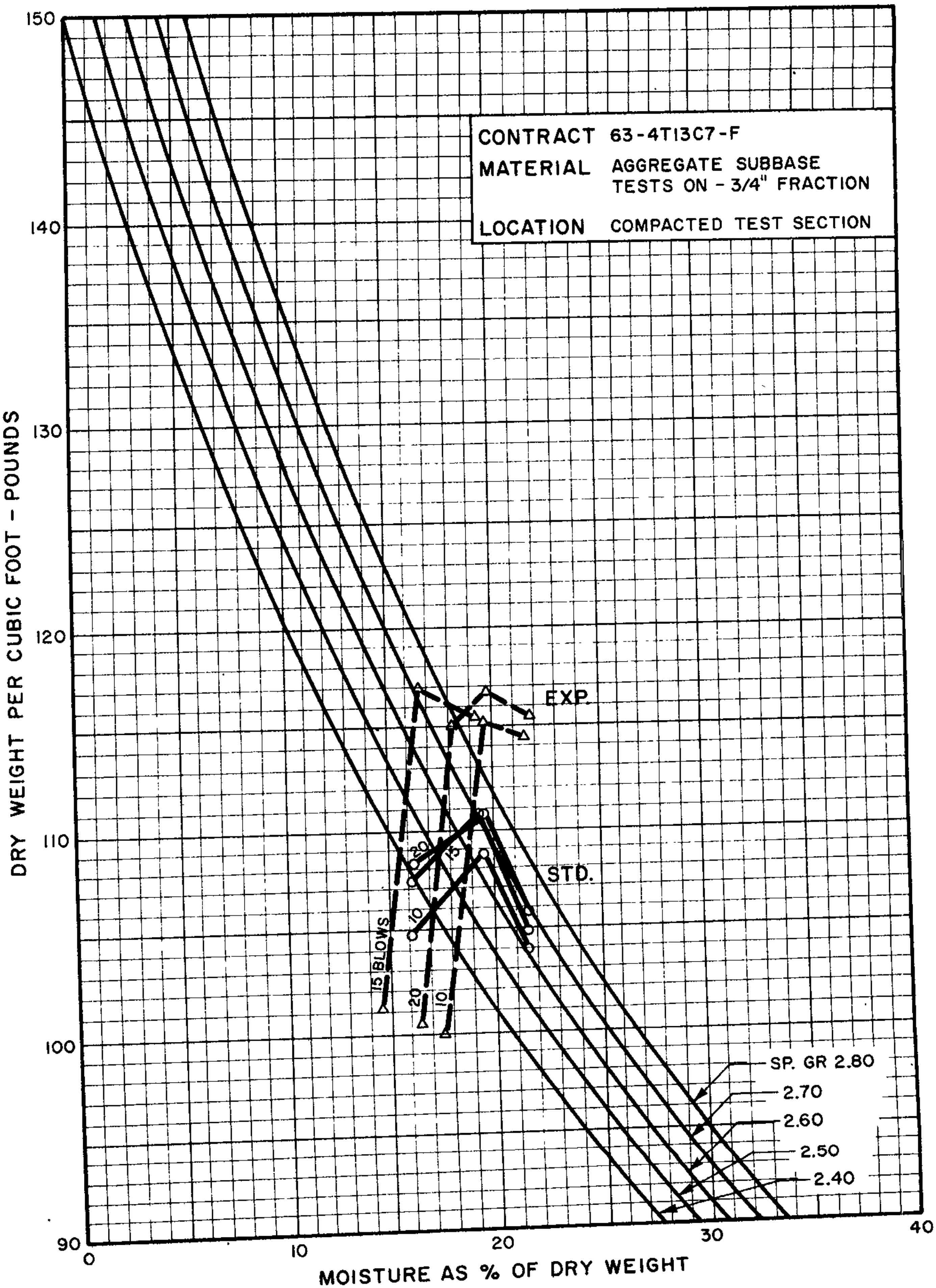
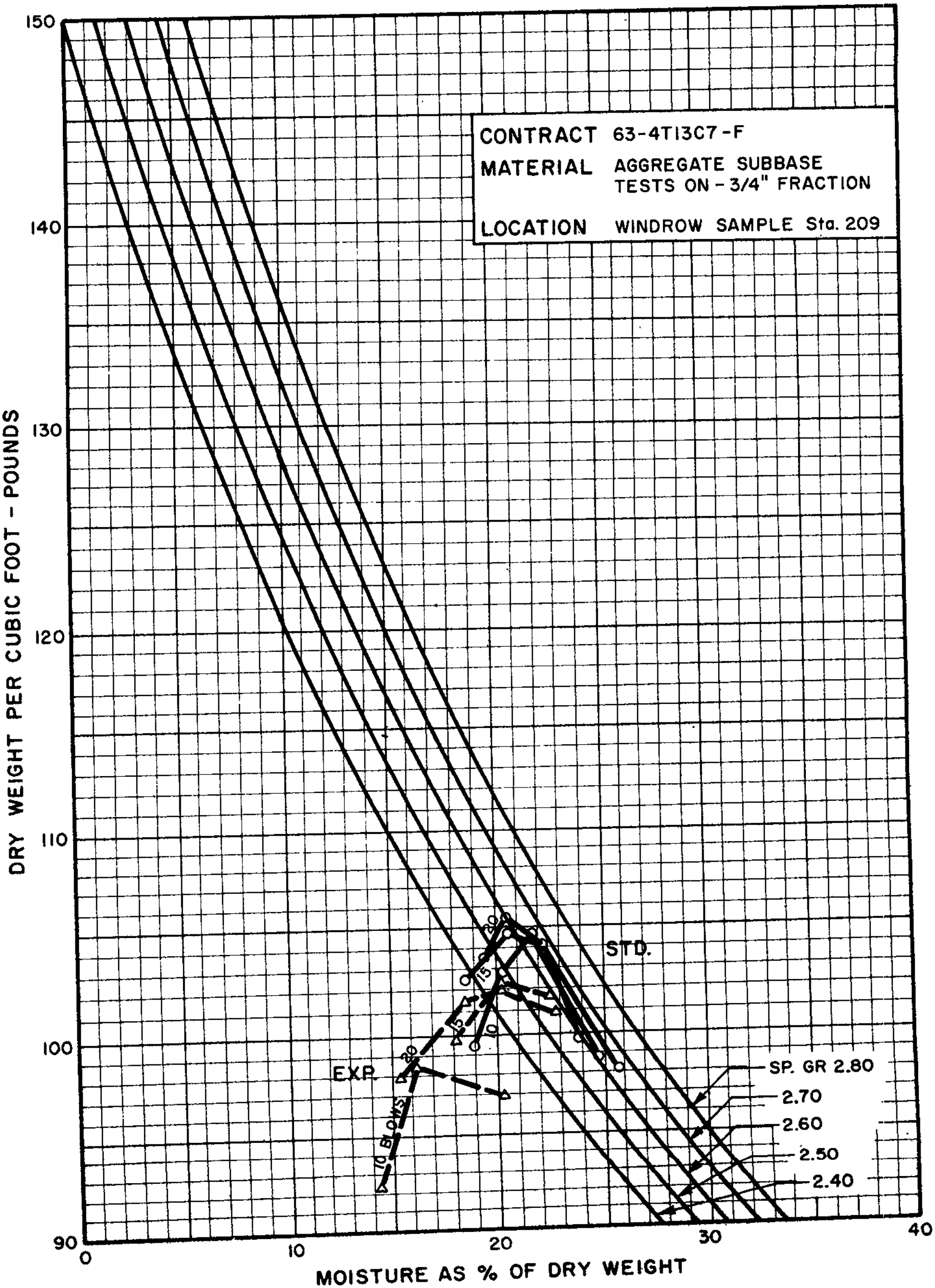

CONTRACT 63-4T13C7-F
MATERIAL AGGREGATE SUBBASE TESTS ON - 3/4" FRACTION
LOCATION COMPACTED TEST SECTION
EXP.
STD.
15 BLOWS
20
15
10
20
10
SP. GR 2.80
2.70
2.60
2.50
2.40
DRY WEIGHT PER CUBIC FOOT - POUNDS
MOISTURE AS % OF DRY WEIGHT
150
140
130
120
110
100
90
0
10
20
30
40

Figure I



CONTRACT 63-4T13C7-F
MATERIAL AGGREGATE SUBBASE
TESTS ON - 3/4" FRACTION
LOCATION WINDROW SAMPLE Sta. 209
DRY WEIGHT PER CUBIC FOOT - POUNDS
150
140
130
120
110
100
90
0
10
20
30
40
MOISTURE AS % OF DRY WEIGHT
STD.
EXP.
10 BLOWS
SP. GR 2.80
2.70
2.60
2.50
2.40

Figure II

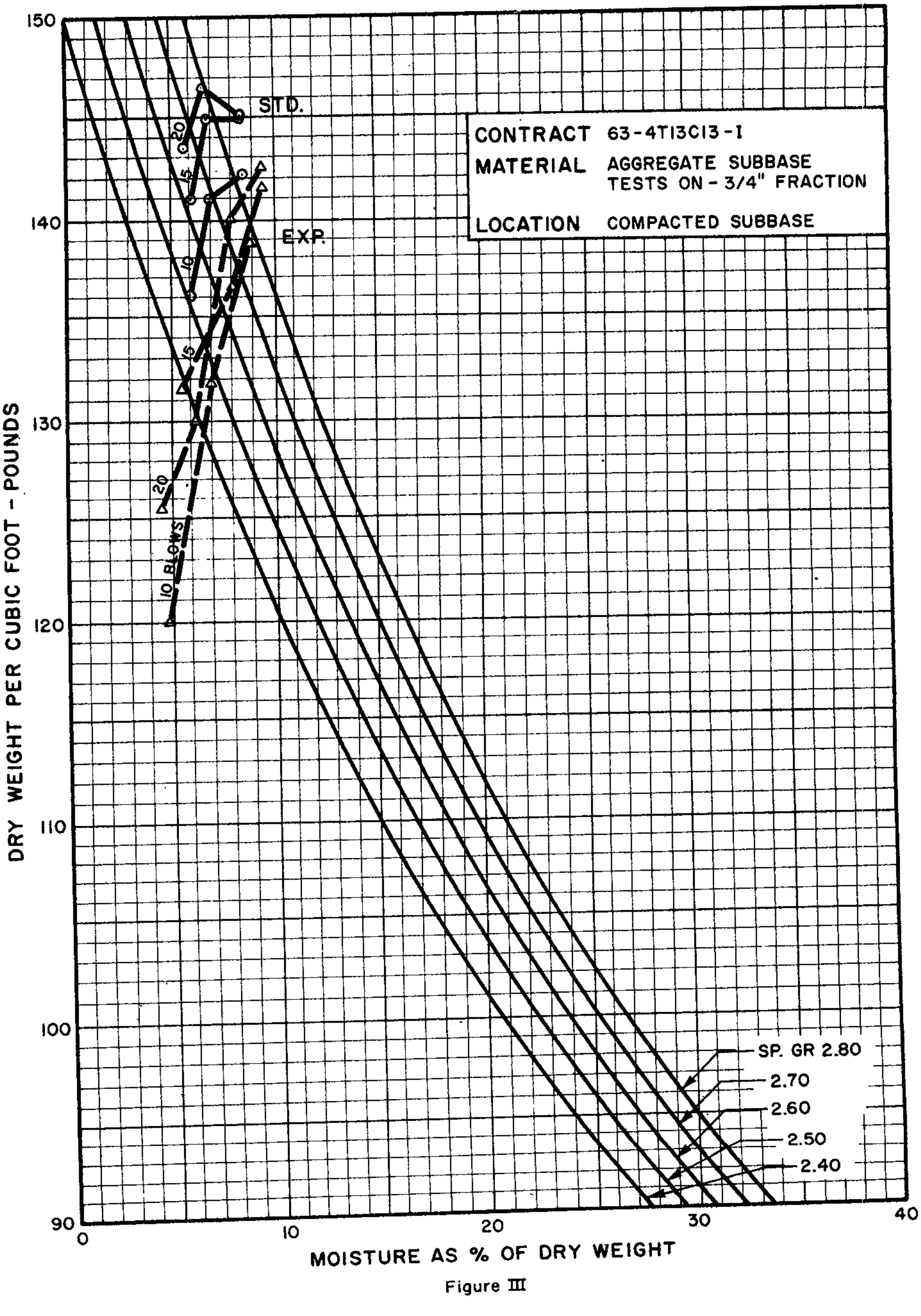
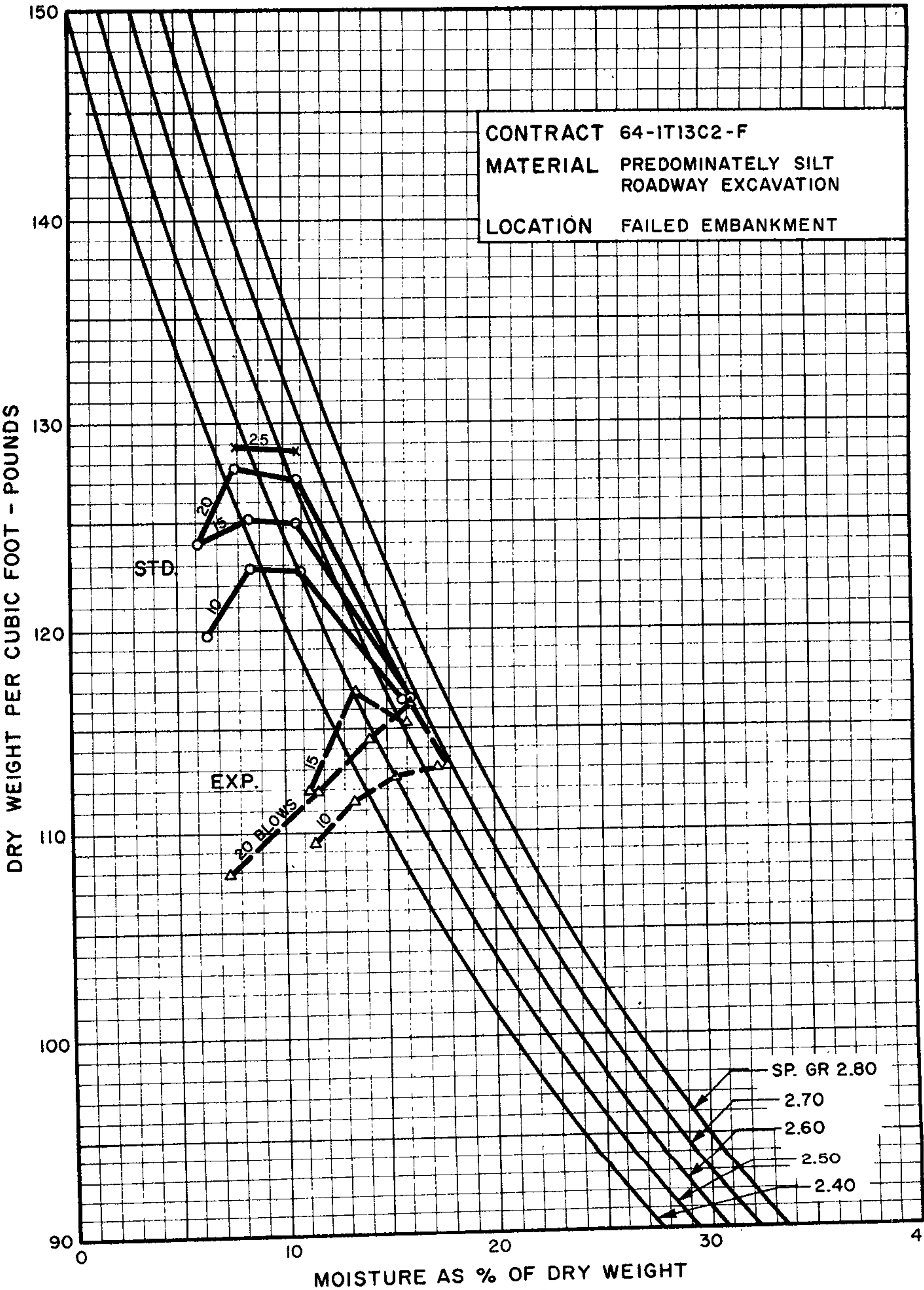

CONTRACT 63-4T13C13-I
MATERIAL AGGREGATE SUBBASE
TESTS ON - 3/4" FRACTION
LOCATION COMPACTED SUBBASE
STD.
EXP.
20
15
10
15
20
10 BLOWS
SP. GR 2.80
2.70
2.60
2.50
2.40
DRY WEIGHT PER CUBIC FOOT - POUNDS
MOISTURE AS % OF DRY WEIGHT
150
140
130
120
110
100
90
0
10
20
30
40

Figure III


CONTRACT 64-1T13C2-F
MATERIAL PREDOMINATELY SILT ROADWAY EXCAVATION
LOCATION FAILED EMBANKMENT
DRY WEIGHT PER CUBIC FOOT - POUNDS
MOISTURE AS % OF DRY WEIGHT
150
140
130
120
110
100
90
0
10
20
30
40
STD.
EXP.
25
20
15
10
15
20 BLOWS
10
SP. GR 2.80
2.70
2.60
2.50
2.40
Figure IV

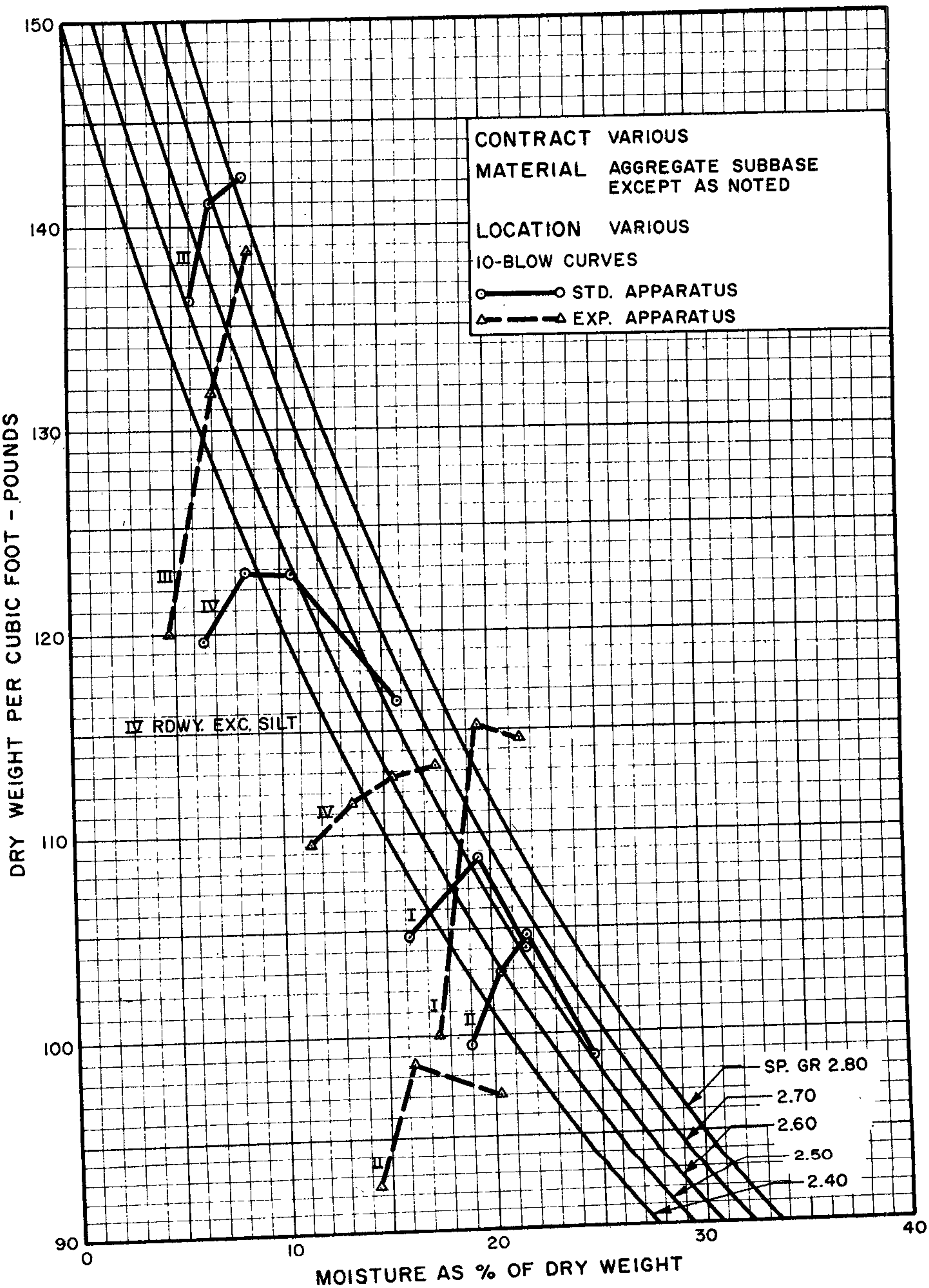
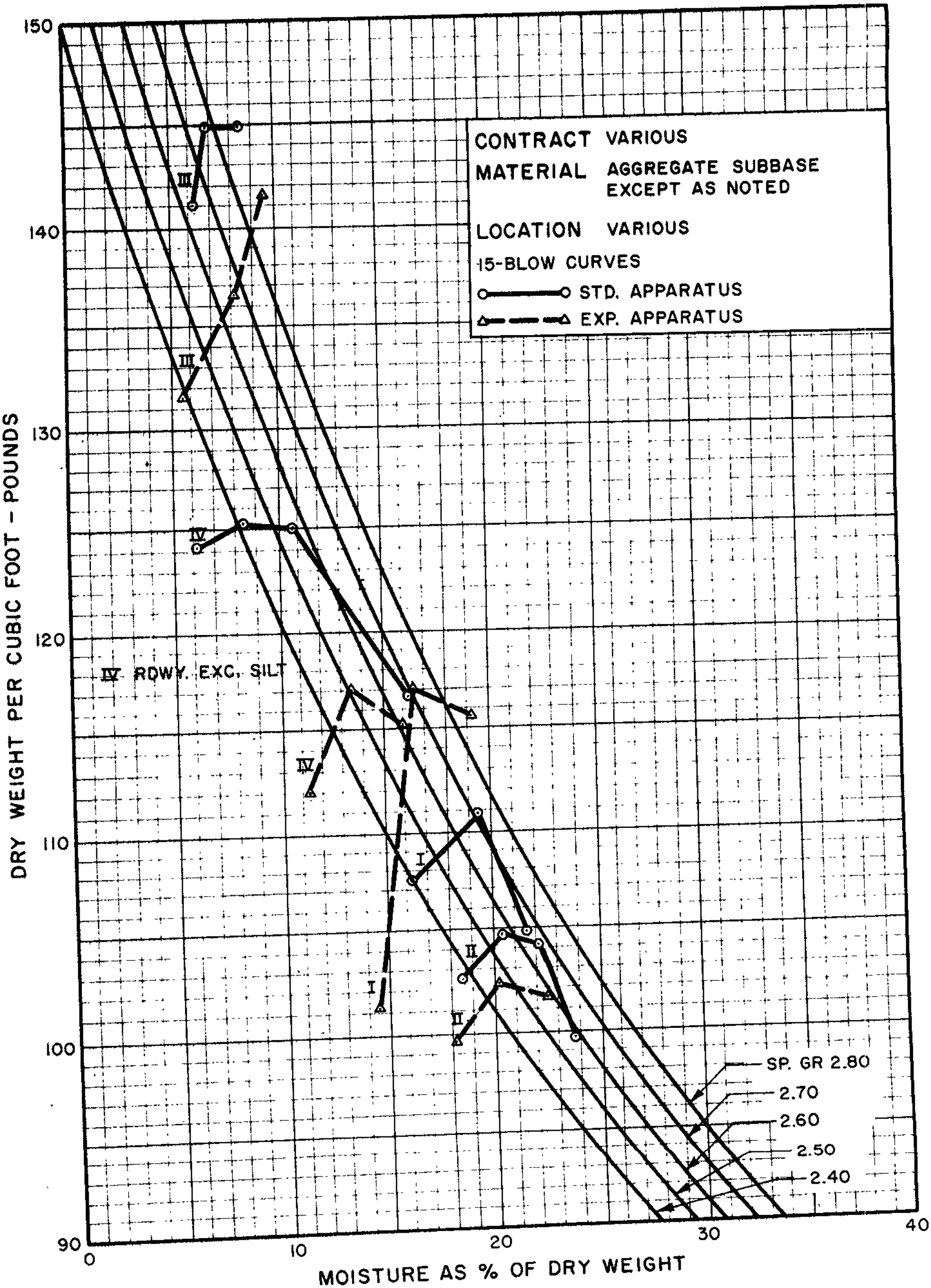

CONTRACT VARIOUS
MATERIAL AGGREGATE SUBBASE EXCEPT AS NOTED
LOCATION VARIOUS
10-BLOW CURVES
STD. APPARATUS
EXP. APPARATUS
IV RDWY. EXC. SILT
SP. GR 2.80
2.70
2.60
2.50
2.40
DRY WEIGHT PER CUBIC FOOT - POUNDS
MOISTURE AS % OF DRY WEIGHT

Figure V



CONTRACT VARIOUS
MATERIAL AGGREGATE SUBBASE EXCEPT AS NOTED
LOCATION VARIOUS
15-BLOW CURVES
STD. APPARATUS
EXP. APPARATUS
IV RDWY. EXC. SILT
SP. GR 2.80
2.70
2.60
2.50
2.40
DRY WEIGHT PER CUBIC FOOT - POUNDS
MOISTURE AS % OF DRY WEIGHT

Figure VI

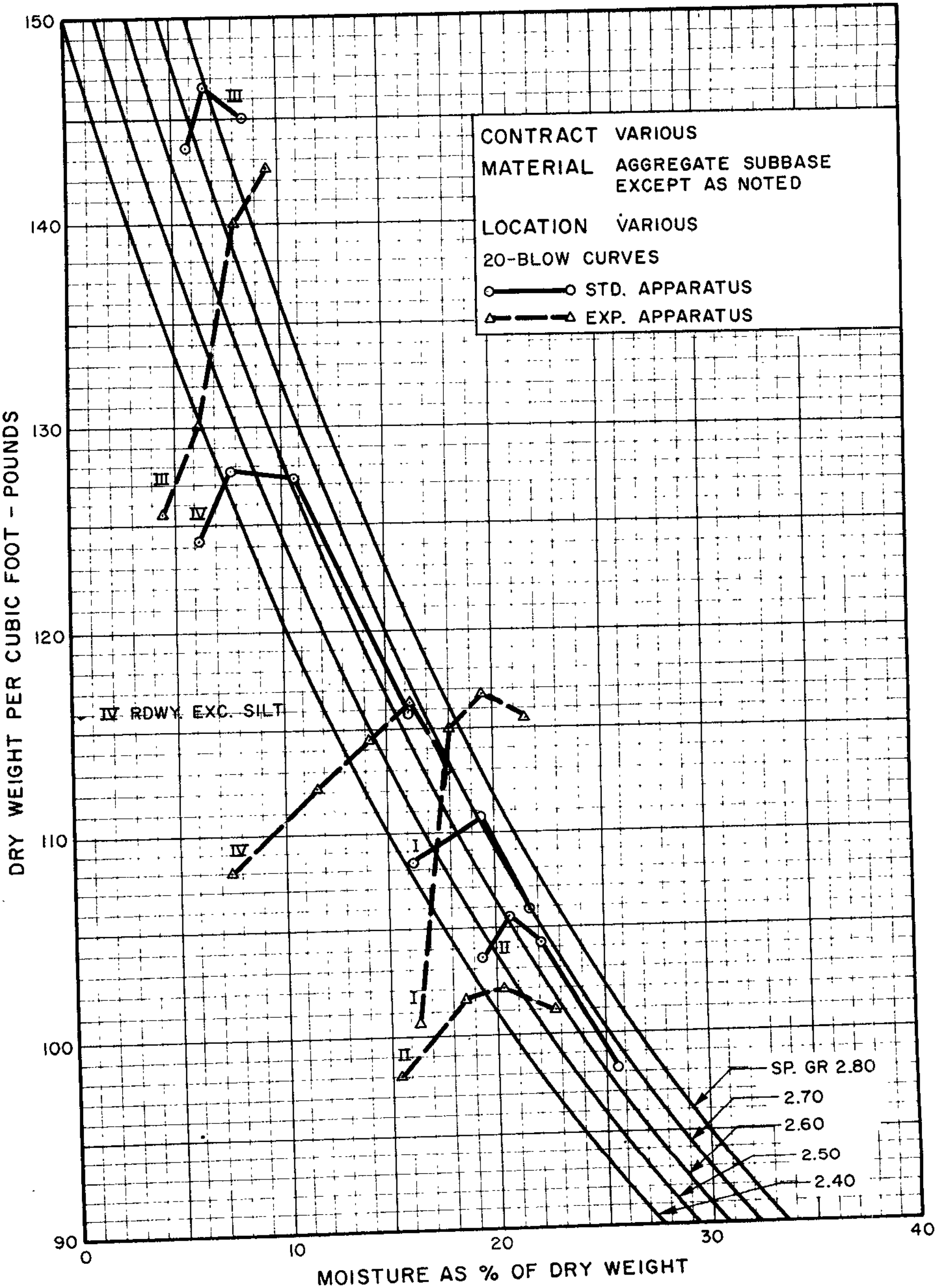
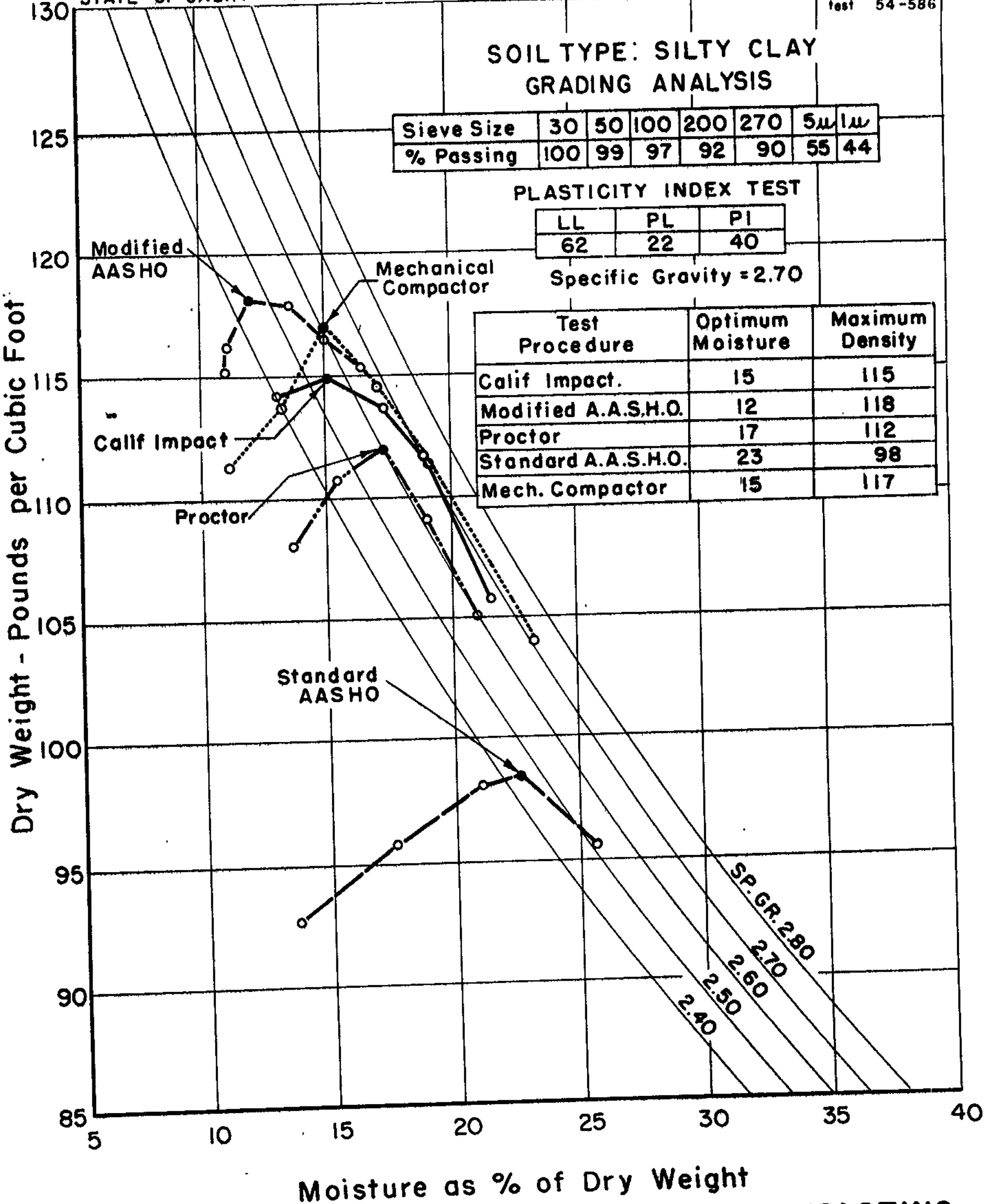

CONTRACT VARIOUS
MATERIAL AGGREGATE SUBBASE EXCEPT AS NOTED
LOCATION VARIOUS
20-BLOW CURVES
STD. APPARATUS
EXP. APPARATUS
IV RDWY. EXC. SILT
SP. GR 2.80
2.70
2.60
2.50
2.40
I
II
III
IV
DRY WEIGHT PER CUBIC FOOT - POUNDS
MOISTURE AS % OF DRY WEIGHT
150
140
130
120
110
100
90
0
10
20
30
40

Figure VII

STATE OF CALIF. MATERIALS & RESEARCH DEPARTMENT DIV. OF HIGHWAYS

test 54-586



Sieve Size	30	50	100	200	270	5μ	1μ
% Passing	100	99	97	92	90	55	44

LL	PL	PI
62	22	40

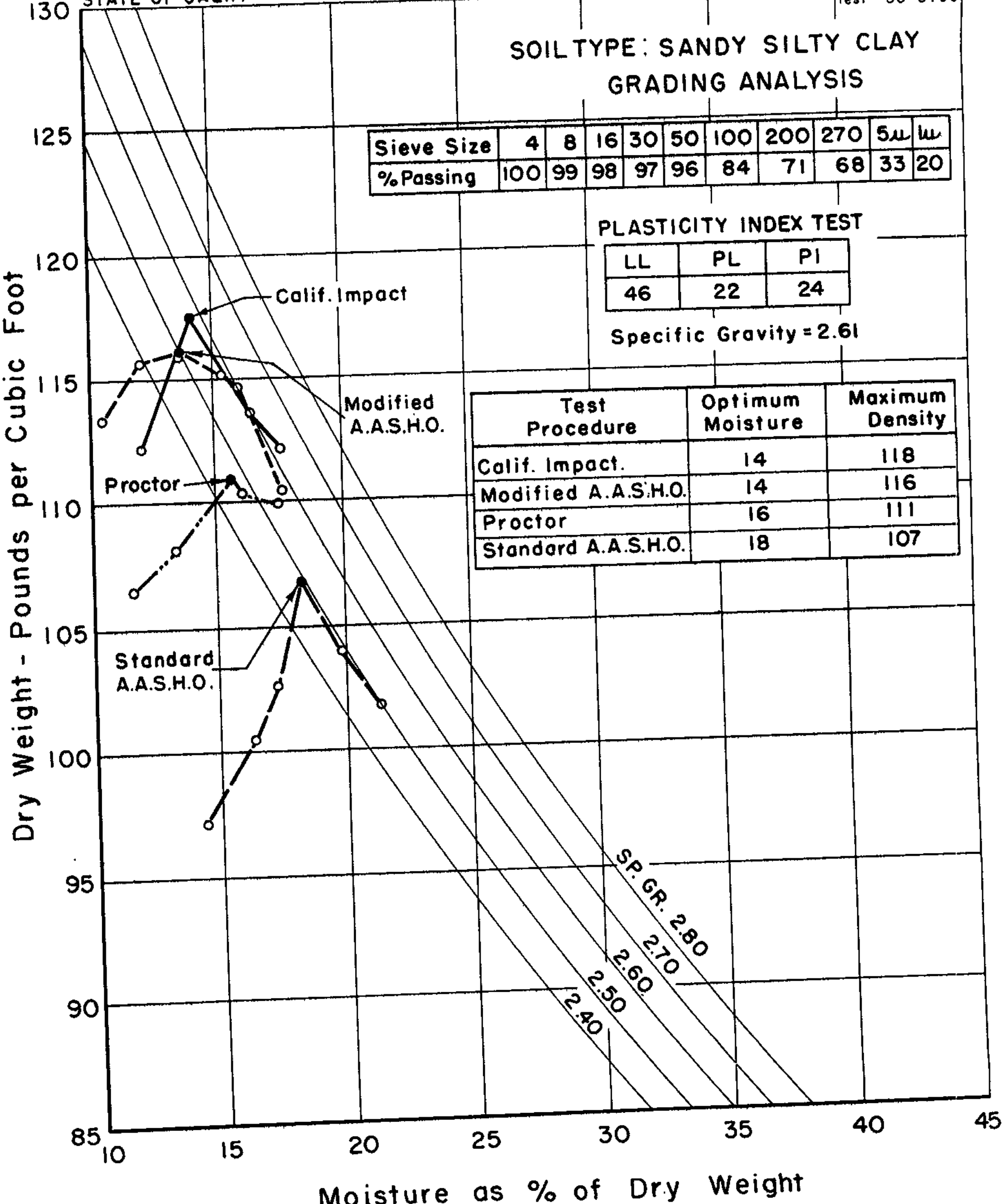
Test Procedure	Optimum Moisture	Maximum Density
Calif Impact.	15	115
Modified A.A.S.H.O.	12	118
Proctor	17	112
Standard A.A.S.H.O.	23	98
Mech. Compactor	15	117

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES

Sheet A

STATE OF CALIF. MATERIALS & RESEARCH DEPARTMENT DIV. OF HIGHWAYS

test 53-3799



Sieve Size	4	8	16	30	50	100	200	270	5μ	1μ
% Passing	100	99	98	97	96	84	71	68	33	20

LL	PL	PI
46	22	24

Test Procedure	Optimum Moisture	Maximum Density
Calif. Impact.	14	118
Modified A.A.S.H.O.	14	116
Proctor	16	111
Standard A.A.S.H.O.	18	107

COMPARISON OF VARIOUS LABORATORY COMPACTING PROCEDURES

Sheet B